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ORIGINAL PAPER

Cost-effectiveness analysis of subsidy schemes for industrial timber development and carbon sequestration in Japanese forest plantations

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Abstract: This study uses simulations to investigate the effects of implementing two different Japanese forestry subsidy systems on timber production and carbon stock, and examines the consequences for harvesting strategies. An existing Local Yield Table Construction System (LYCS), a wood conversion algorithm, and a harvesting cost model were used in the simulations to test the applicability of different subsidies to the thinning of stands. Using forest inventory data collected by local government staff, simulation output was used to calculate forestry profits, carbon stocks, subsidies, the amount of labor required, and the cost effectiveness of investing in subsidies. By comparing the output of simulations based on two scenarios, we found that both the clear-cutting area and the amount of harvested timber were larger under Scenario 2, in which the rules governing subsidy allocations are more relaxed, than under Scenario 1, in which the rules are more restrictive. Because the harvested timber under Scenario 1 was mainly produced by clear-cutting, the forestry profits and the subsidy predicted in the early period of the simulation, were larger under Scenario 1 than under Scenario 2. In contrast, the carbon stock was larger under Scenario 2 than under Scenario 1. The simulation model is likely to be useful for improving Plan-Do-Check-Act cycles implemented in Japanese forest management systems.

Key words: carbon stock; forestry profits; subsidy; timber production

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Introduction

In response to current concerns over climate change, carbon emissions need to be reduced. Managing forests sustainably and accounting for their value as carbon sinks in terms of the biomass of forest trees, can make an important contribution to this goal. The public benefits arising from timber production and carbon sequestration in forested areas have recently been recognized in many parts of the world including the United States (Sakata 2005; Foley et al. 2009; Ehman 2002; Im 2007), Europe (Backe'us et al. 2005; Sivrikaya 2007; Kaipainen2004; Seidl et al. 2007; Raymer et al. 2009; Pohjola and Valsta 2007), Canada (Hennigar 2008; Thompson 2009; McKenney et al. 2004), Oceania （Campbell 2004) and Asia (Ravend 1995; Han 2009). Forests not only have economic value from the commercial production of timber, but are also of value to the public through their important environmental functions including their roles as carbon sinks, contributing to biodiversity, and protecting water resources (Pukkala 2002). Since forest management is subsidized by the taxpayer through the national budget, it must take into consideration the public benefits of forestry by restricting the area of clear-cutting and certain other silvicultural treatments. Because profits decrease with the decreasing price of timber (Forestry Agency 2007), almost all forest owners in Japan depend on subsidies (Komaki 2006; Nakajima et al. 2007b). Previous studies have indicated that the amount of various silvicultural practices undertaken in an area, including planting, weeding, pruning, pre-commercial thinning, and the thinning area, can be strongly correlated with the amount of national subsidy available (Hiroshima and Nakajima 2006). It is therefore necessary to bring forest plantations that are dependent on national subsidies, into a condition whereby they provide high levels of benefit to the public in Japan.

Under the global policy framework of the Kyoto Protocol, the carbon sink value of forests is calculated both in terms of forests which have undergone aforestation, reforestation and deforesta-

tion (ARD forests) since 1990, as described by Article 3.3, and in terms of managed forests that have been subjected to silvicultural practices since 1990 (FM forests) under Article 3.4. Japan is currently preparing to report emissions and removals of carbon from forests in accordance with the Good Practice Guidance for Land Use, Land-Use Change, and Forestry (GPG-LULUCF) (Houghton et al. 1997; IPCC 2000; IPCC 2007). Based on attitudes since the Kyoto Protocol was first enforced, Japanese citizens are expected to consider that the most important function of forests is their role as carbon sinks (Forestry Agency 2007). Consequently, some studies (Hiroshima and Nakajima 2006; Nakajima et al. 2007a) have investigated the effects of the subsidy system on sustainable management for maintaining the carbon stock held in the forested areas of Japan, as well as its effects on forestry profits.

In addressing the sustainable management of natural resources, many previous studies (Forest Ecosystem Management Assessment Team 1993; Miles 2008; Butler et al. 2001) have recommended adopting adaptive management procedures including the Plan-Do-Check-Act (PDCA) cycle, which is based on a scientific consensus in order to maintain the sustainability of large forest areas at a global scale (Millennium Ecosystem Assessment Board 2005) in such regions as the United States (Beier et al. 2009), Europe (Folke et al. 2005; Bolte 2009), Russia (Elbakidze et al. 2010), Africa (Kalibo and Medley), and Asia (Menzies 1988; Song et al. 2004).

The PDCA cycle is a useful framework for adaptive management. Under the Plan phase, decision-making is conducted by designing, and selecting from a number of options, management plans that meet specific management purposes. After the Plan phase, the selected plan is implemented in the Do phase. In the Check phase, the outcomes derived from the Do phase are monitored in order to compare predicted and observed results. The Act phase involves the improvement and adjustment of planning based on the evaluation of results derived from the plan implemented and monitored during previous phases (Forest Ecosystem Management Assessment Team 1993; Miles 2008). Although the names and definition of these phases differ slightly in various previous studies (Stankey et al. 2005; Nyberg 1999) the introduction of adaptive management, and the fundamental concept of the management cycle based on PDCA as a process of continual systematic improvement, is a common theme.

However, there are few examples of the successful application of a systematic management cycle at a local scale (Bormann et al. 2007). A long-term PDCA cycle for adaptive management has not yet been implemented in many instances because it is labor intensive and time-consuming and therefore expensive to conduct everywhere it might be advisable to do so. When addressing challenging societal problems with adaptive management based on PDCA, important decisions have to be made concerning how to balance the competing goals of the cost-effectiveness of a program, its feasibility, and its economic and objective outcomes (Butler et al. 2001). In the context of the present study, because the Japanese subsidy budget has been limited (Hiroshima and Nakajima 2006), it is especially important to clarify the cost-effectiveness of any subsidy system when considering the development of a rational forestry policy.

The present study therefore aims to investigate the cost-effectiveness of the Japanese forestry subsidy system by simulating its effects on timber production, carbon stocks and other factors that need to be considered in a PDCA management cycle. Because the simulation output is also used to assess the cost-effectiveness of investments in forestry and carbon stock, we also discuss the usefulness of these simulations for the PDCA cycle used by regional forest management systems.

Materials and methods

Study site

The study site was a forest plantation in Morotsuka village, in the Miyazaki Prefecture, which is located in southern part of Japan (Fig. 1) and which produces the largest quantity of timber products in the country. Morotsuka village is located in a warm temperate zone, with an average annual temperature of approximately 14 °C and average annual rainfall of about 2 445 mm. Forests cover a total area of 17 785 ha in the prefecture, with 12 541 ha in the forest plantation of Morotsuka village, of which 11 629 ha (92.7%) are Japanese cedar (*Cryptomeria japonica*), and 912 ha (7.3%) are hinoki (*Chamaecyparis obtusa*) (Miyazaki Prefecture Government 2008). A forest inventory of real data, linked to a geographic information system containing layers of data relating to the private forests in Morotsuka village, is updated annually by staff members of the Miyazaki Prefectural government and the Mimi river valley forest association and was available for use in this study. The targeted areas are forest plantations that are mainly occupied by *Cryptomeria japonica* between 30 and 50 years old (Fig. 2). This area was one of the forest projects formally identified in Japan's Verified Emission Reduction system (J-VER), which is a Japanese carbon offset system. Morotsuka village forest already has Forest Stewardship Council (FSC) certification, which was one of the conditions required to generate credits under the J-VER system in 2004. It is important, therefore, to establish a sustainable forest management system that takes into consideration timber production and the amount of carbon stock held in the area.

In the private forest sites where the present study was conducted, thinning was undertaken by forestry workers of the forestry cooperative. A national subsidy system for the thinning of all planted tree species is commonly applied, but mainly to forest plantations less than 35 years old. The grant rates of the subsidy systems cover approximately 70% of the cost of thinning.

Inventory data relating to the private forests, such as stand age, area, tree species, slope, address of forest owners and site index (Nakajima et al. in press), were available and were also linked to each sub-compartment included in the geographic information system (GIS).

Analytical tools

The analytical tools used in this study were as follows. For esti-

mating carbon absorbed by forests, we referred to the J-VER guidelines (Environmental Ministry 2009), which are based on the carbon accounting system of the Kyoto Protocol. J-VER guidelines allow the use of the Local Yield Table Construction System (LYCS), which simulates timber growth and carbon stock (Environmental Ministry 2009). This growth model is applicable to the main tree species, including sugi (*Cryptomeria japonica*), hinoki (*Chamaecyparis obtusa*), karamatsu (*Larix leptolepis*) and todomatsu (*Abies sachalinensis*), which are planted throughout Japan (Shiraishi 1986; Nakajima et al. 2009c; Nakajima et al. 2010; Nakajima et al. in press). By combining LYCS with a wood conversion algorithm and a harvesting cost model (Nakajima et al. 2009a; 2009b), we can predict not only carbon stock but also harvested timber volume and forestry income. The stand age, tree species, and site index included in the forest inventory data can be used as input data for the LYCS. The harvest and silvicultural practice records of the study site, including details of incomes, costs, and labor, were used to estimate forestry profits and labor requirements for harvesting and silviculture. The unit price of subsidies depends on the standard silviculture system (Miyazaki Prefecture Government 2008). Historical records of the amount of labor required to carry out various silvicultural practices including silviculture treatments (planting, weeding, pruning, pre-commercial thinning) and harvesting (thinning, clear-cutting) were also available from Mimi river valley forest association.

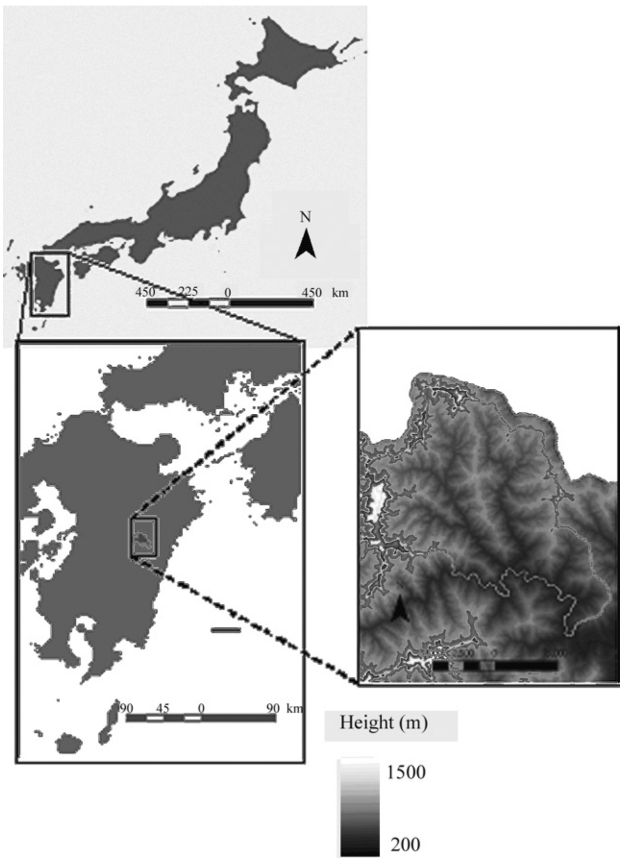


Fig. 1 Location of Morotsuka village, showing an elevation of the study site. The blue line shows the forest boundary line of Morotsuka village

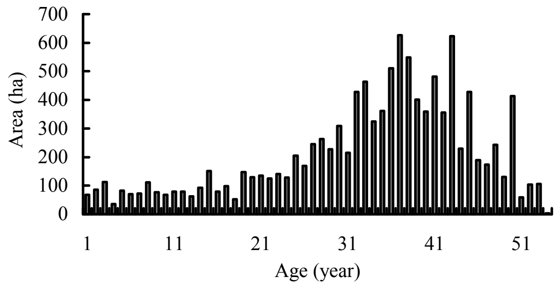


Fig. 2 The age distribution of forested areas in the study site

Data analysis

In the present study, we investigate through simulation modeling the effects of the Japanese forestry subsidy system on timber production, carbon stock holdings, subsidy, and the amount of labor required for the final cutting area. Two subsidy system scenarios were assumed: Scenario 1 was the traditional subsidy applied to stands less than 35 years old (Nakajima et al. 2007a); Scenario 2 was the subsidy applied to stands of any age. Basically, Scenario 1 is the Japanese traditional forestry subsidy system that has been applied to non-commercial silviculture: i.e. non-commercial harvesting conducted in stands less than 35 years old; regeneration; and stand establishment including planting, pruning, weeding and pre-commercial thinning. However, the international pledge made under the Kyoto Protocol commitments (Houghton et al., 1997; UNFCC, 1998; UNFCC, 2002), requires a 6 % reduction of CO_2 emissions from the 1990 level, of which 3.8 % may be attributed to carbon absorption by means of ‘forest management’ (Hiroshima 2004; Forestry Agency 2007). Increasing the area of ‘forest management’ as described under article 3.4 in the Kyoto Protocol, requires pre-commercial or commercial thinning (Nakajima et al. 2007a). Therefore, to fulfill Japan’s international pledge under the Kyoto Protocol in a global context (Hiroshima and Nakajima et al. 2006), it has been proposed that a new subsidy system (i.e. Scenario 2) can be applied not only to non-commercial silviculture, but also to commercial thinning conducted in stands of any age. This will promote thinning and restrict large-scale clear cutting by supporting long-rotation silviculture (Forest Agency 2007).

Based on the assumptions of the two scenarios, the harvesting area, amount of harvested timber, subsidy, forestry profits, carbon stock and quantity of labor were calculated by using an existing stand growth model (Nakajima et al. 2010), a wood conversion algorithm (Nakajima et al. 2009b) and a forestry cost model (Nakajima et al. 2009a). With data describing the stand condition (stand age, site index and tree species), the thinning plan (thinning ratios, number of thinnings and the thinning age) and the timber price as model inputs, the future stand volume, timber volume and forestry profits can be generated as model output (Nakajima et al. 2009a, 2009b, 2010).

The accuracy of the basic model for predicting future stands has been exhaustively checked by comparing estimated tree growth with observed tree growth data in permanent plots (Ohmura et al. 2004) gathered over more than 30 years (Shiraishi 1986; Nakajima et al. 2010). Because the period of validation over which

these previous studies were conducted was longer than the prediction period of 25 years adopted in the present study, estimates of future timber production and forestry profits (Nakajima et al. 2009a; 2009b) could be calculated based on predictions of future tree growth at the level of stands. Predictions at the forest level could then be estimated by summarizing the predicted values at the stand level. If the predicted values derived from existing models at the stand level are accurate, it follows that the predicted value at the forest level, which is the sum of values at the stand level, would be also accurate.

By inputting the stand condition derived from forest inventory data into these models, the future forestry profits could be estimated as a function of the harvesting plan strategies and the timber price. However, because it is not easy to predict inflation and timber price fluctuations precisely, we assume in the model that the socio-economic situation driving these variables is constant. We therefore assume that timber price remains constant throughout the prediction period and is as described by a previous study (Nakajima et al. 2009a). We believe this assumption is justified since a survey by the forest association, and government reports (Miyazaki Prefecture Government 2008) indicate that the current annual average timber price has been stable over recent years. The final age at cutting was chosen to maximize the present net value of forestry profits, estimated from those valid at the most recent final cutting. The discount rate was then estimated relative to a value considered to be reasonable to society; in this case 3.0% was considered reasonable as this represents the average long-term yield of Japanese government bonds (Tokyo Stock Exchange 2007). Although the thinning plan is included in the input data as mentioned above, it can be changed according to a particular stand density control strategy. The optimum thinning plan was decided upon by selecting the one which maximized the net present value. We varied the thinning ratios by 5 % increments from 20% to 40% in line with the existing standard silviculture systems (Miyazaki Prefecture Government 2008). We also varied the number of thinnings between zero and three, and the thinning age by increments of 5 years between the initial stand age and the final age at cutting. By inputting these various thinning plans into the LYCS, we simulated forestry profits under all harvesting strategies. We then selected the cutting plan that maximized the present net value of forestry profits for each sub-compartment.

The total harvesting area and the quantity of harvested timber were calculated by summarizing their respective values based on the harvesting plans calculated for each of the two existing subsidy scenarios. The subsidies were estimated by summarizing the silviculture and thinning subsidies derived from government subsidy unit prices. The total forestry profits could then be estimated from the forestry income and the subsidy. The carbon stocks were also estimated by substituting stand volumes derived from LYCS into the following formula (Environmental Ministry 2009):

$$C = E \cdot D \cdot V(f) \tag{1}$$

where: C is the carbon stock (tonnes ha^{-1}), E is a biomass expansion factor, D is the wood density (tonnes/m^3), and $V(t)$ is the stand volume (m^3·ha^{-1}). These variables, including *E* and *D,* were derived from a previous study by Fukuda et al. (2003).

In addition, labor requirements were calculated by multiplying the amount of labor required per hectare for each silvicultural practice, by the area over which that silviculture would be practiced, based on the estimated harvesting plans and the age distribution of trees in the study site. For descriptive purposes, the prediction period was set at 25 years, which is the period required for future natural resource predictions by the Japanese Ministry of Education, Culture, Sports, Science and Technology (Science Council 2008). The simulation started from 2010. The cost-effectiveness of any forestry investment was calculated by dividing the forestry profits or value of carbon stock by the annual subsidy applied. The usefulness of these simulations for the Plan-Do-Check-Act (PDCA) cycle (Nakajima et al. 2007b) for forest management systems is discussed below.

Results

Fig. 3 shows that the average stand age at clear-cutting was 46 years and 51 years under Scenarios 1 and 2, respectively. The age classes at clear-cutting ranged from 8 – 11years under Scenario 1, and from 8 – 15 years under Scenario 2. Under Scenario 1, profits from stands in an age class greater than 4 (36 years old) could be derived from harvest income alone, while under Scenario 2 profits could only be derived from harvesting income and subsidies. Thus, under Scenario 2 the age at clear-cutting needs to be greater than under Scenario 1 in order to increase total forestry profits, including subsidies and clear-cutting income derived from the larger timber harvested from older stands. Figure 4 shows the harvesting area under the two different scenarios. The increase in the potential harvesting area is derived from the increasing area of mature forest as the age distribution of stands in the study site changes over time. A comparison of the two scenarios clearly reveals a larger clear-cutting area under Scenario 1 than under Scenario 2, the difference ranging between 79 ha and 320 ha. After 2020, the magnitude of the difference in clear-cutting areas decreased by up to 24.9% of its maximum value. In contrast, the thinning area under Scenario 2 is clearly larger than under Scenario 1, with the difference ranging between 0 and 412 ha. These results show that the harvesting practices under the scenarios 1 and 2 were mainly clear cutting and thinning, respectively.

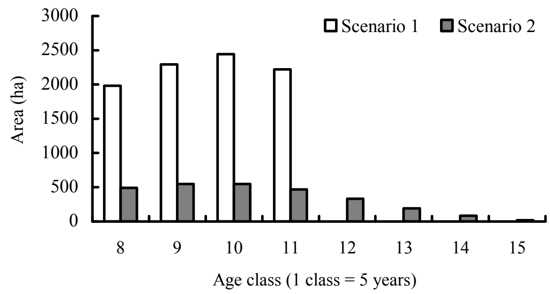
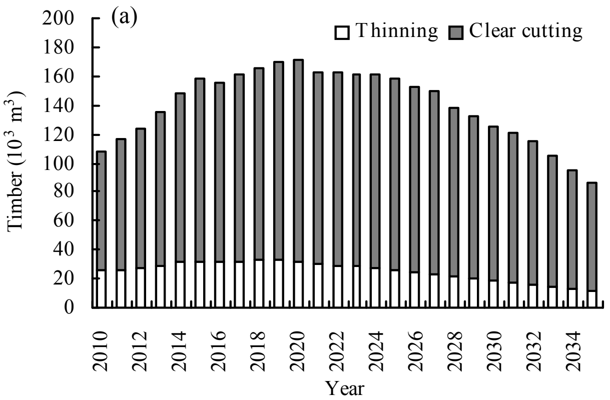


Fig. 3 The age distribution of final cutting area under different scenarios. White and black blocks show the final cutting area under Scenarios 1 and 2, respectively.

Timber production

Fig. 5 shows the differences in volumes of harvested timber under the two scenarios. Under Scenario 1, the harvest of clear-cutting timber was larger than that of thinning timber, with a ratio of the clear–cutting to thinning timbers ranging from 76:24 in 2010 to 86:14 in 2033. After 2020, the volume of harvested timber decreased by up to 50.2 % of its maximum value. In 2035 the volume of harvested timber was 79.4 % of its 2010 value due to a decrease of harvesting area (Fig. 4a) for clear-cutting.



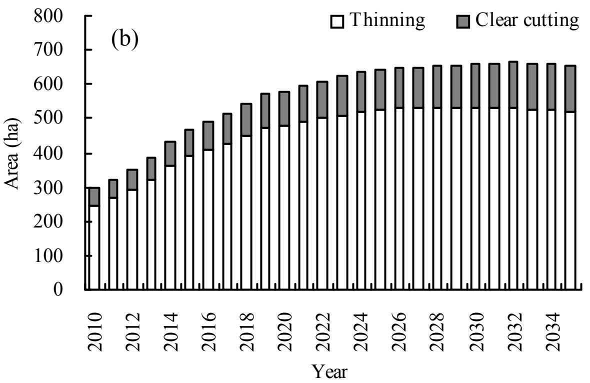
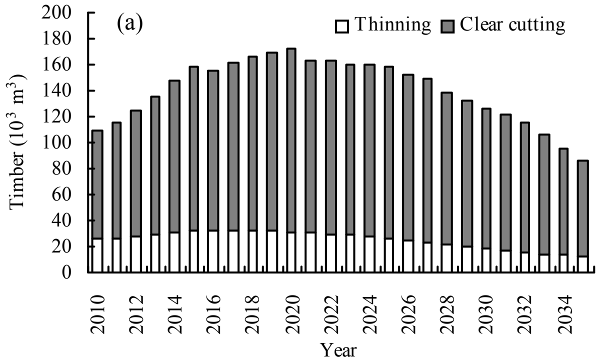


Fig. 4 The clear-cutting and thinning harvesting areas under (a) Scenario 1 and (b) Scenario 2. White and black blocks show the thinning and clear-cutting harvesting areas, respectively.

Under Scenario 2 the clear–cut timber harvest was smaller than that of thinned timber with the ratio of the clear–cut to thinned timber ranging between 37:63 in 2010 to 45:55 in 2035. The harvested timber volume increased by up to 286.3% of its minimum value between 2010 and 2035 due to an increasing of harvesting area (Fig. 4b). Although the total volume of harvested timber under Scenario 1 was larger than that under Scenario 2 up to 2032, in 2033 the pattern was reversed.

A comparison of the two scenarios clearly shows that the harvested volume of clear-cut timber was larger under Scenario 1 than Scenario 2, with differences ranging between 21.1 and 106.3 $\times 10^3$ m^3. After 2020, the difference between volumes of clear-cut timber decreased by up to 19.9% of its maximum value. In contrast, the volume of thinned timber harvested under Scenario 2 was clearly larger than under Scenario 1, with differences ranging between 0 and 51.6 $\times 10^3$ m^3. These results show that production was predominantly of clear-cut timber under Scenario 1 and thinned timber under Scenario 2. Comparing Figs 4 and 5 it was found that the ratio of clear-cut timber to total harvested timber was higher than the ratios of their respective harvested areas, indicating that the volume of harvested timber per unit of harvested area was larger for clear-cut timber than thinned timber.



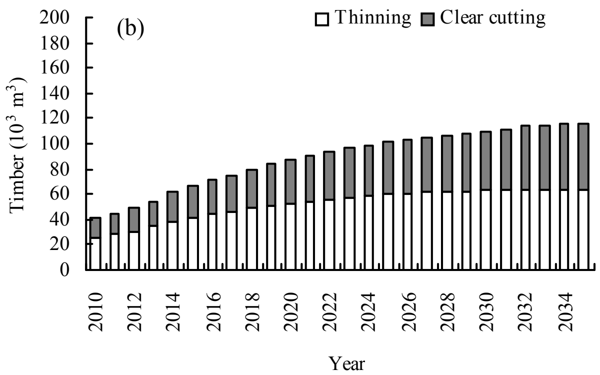


Fig. 5 The clear-cutting and thinning harvested timber volume under (a) Scenario 1, and (b) Scenario 2. White and black blocks show the thinning and clear-cutting harvested timber volume, respectively.

Subsidy

Fig. 6 shows how subsidies vary depending on the scenario. Under Scenario 1, the maximum and minimum subsidies were 616.4 million yen (M¥) in 2022 and 186.3 M¥ in2011; the maximum and minimum silviculture subsidies were 548.1 M¥ in 2022 and 123.2 M¥ in 2011; and the maximum and minimum thinning subsidies were 76.5 M¥ in 2019 and 27.5 M¥ in 2035. Under Scenario 1 the silviculture subsidy was larger than thinning subsidy, with the ratios ranging from 66:34 in 2011 to 94:6 in 2035. After 2022, the subsidies decreased by up to 72.9% of their maximum value due to a decrease in the harvesting area (Fig. 4a) for clear-cutting. The subsidy in 2035 was 204.0% of the subsidy in 2010.

Under Scenario 2 the maximum and minimum subsidies were 316.9 M¥ in 2034 and 189.9 M¥ in 2011; the maximum and minimum silviculture subsidies were 185.5 M¥ in 2034 and 123.2 M¥ in 2011; and the maximum and minimum thinning subsidies

were 133.3 M¥ in 2032 and 61.5 M¥ in 2010. Under Scenario 2 the silviculture subsidy was larger than thinning subsidy with ratios of silviculture and thinning subsidies ranging from 54:46 in 2019 to 72:28 in 2010. Subsidies increased by up to 166.9% of their minimum value over the period of simulated predictions due to an increase in the total harvesting area (Fig. 4b). The total subsidy under Scenario 1 is larger than that under Scenario 2 throughout the prediction period.

A comparison of the two scenarios shows the silviculture subsidy in Scenario 1 to be clearly larger than that of Scenario 2, with differences ranging between 0 and 396.6 M¥. After 2022, the difference of silviculture subsidy decreased by up to 60.1% of the maximum difference, while the thinning subsidy was clearly larger under Scenario 2 than Scenario 1, with differences ranging between 0 and 103.1 M¥.

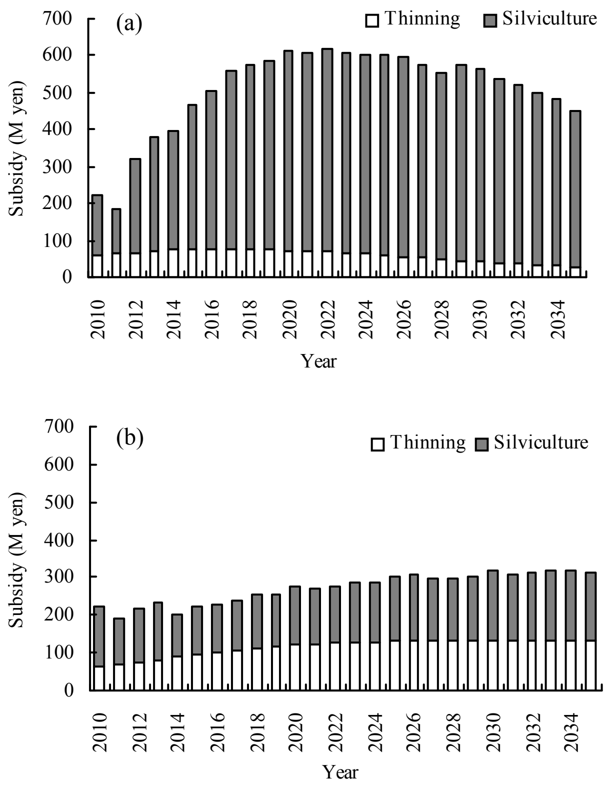


Fig. 6 The silviculture and thinning subsidy under (a) Scenario 1, and (b) Scenario 2. White and black blocks show the thinning and silviculture subsidy, respectively

Forestry profits

Fig. 7 shows the forestry profits under the two scenarios. Under Scenario 1 the maximum and minimum forestry profits were 293.9 M¥ in 2015 and 69.7 M¥ in 2035. After 2015, the forestry profits decreased by up to 23.7% of their maximum values. The forestry profits in 2035 were 27.2 % of those in 2010 due to a decrease of harvesting area (Fig. 4a) for clear-cutting.

Under Scenario 2 the maximum and minimum forestry profits were 214.1M¥ in 2035 and 53.0 M¥ in 2010. Between 2010 and 2035, forestry profits increased by up to 404.0% of their minimum values due to the increased harvesting area (Fig. 4b). Although the total forestry profits under Scenario 1 are larger than under Scenario 2 up to 2027, the pattern was reversed in 2028.

A comparison of the two scenarios shows the forestry profits under Scenario 1 to be larger than under Scenario 2, with differences ranging between 11.1 M¥ and 203.5 M¥. In 2027, the difference between silviculture forestry profits under the two scenarios decreased by up to 5.5 % of their maximum value suggesting that forestry profits under Scenarios 1 and 2 were mainly from clear-cutting and thinning, respectively.

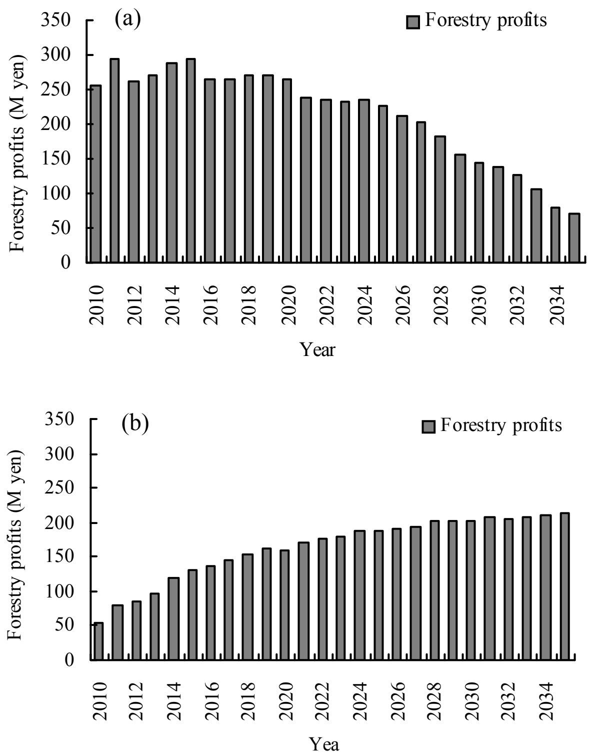


Fig. 7 The forestry profits under (a) Scenario 1, and (b) Scenario 2

Carbon stock

Fig. 8 shows the response of carbon stock to the different scenarios. Under Scenario 1 the maximum and minimum carbon stocks were 1 091.3 thousand tonnes (Kt) in 2010 and 626.8 Kt in 2034. The carbon stock was decreased by up to 57.4% of its maximum value due to the decrease of harvesting area (Fig. 4a) for clear-cutting.

Under Scenario 2 the maximum and minimum carbon stocks were 1 286.5 Kt in 2035 and 1091.3 Kt in 2010. Between 2010 and 2035 carbon stock increased by up to 117.9% of its minimum value due to forest growth (Fig. 4b). The total carbon stock was smaller under Scenario 1 than under Scenario 2 throughout the prediction period.

Generally, the carbon stock under Scenario 2 was relatively more stable than that under Scenario 1. A comparison of the two scenarios clearly shows the carbon stock under Scenario 1 to be smaller than under Scenario 2 with differences ranging between 0

and 658.3 Kt suggesting that differences in carbon stock between the two scenarios were mainly due to clear-cutting. According to the carbon accounting system under the Kyoto Protocol, all carbon stock held as standing timber is counted as being released into the atmosphere by clear-cutting (Hiroshima and Nakajima 2006). Therefore, the larger clear-cutting area (Fig. 4) under Scenario 1 decreased the carbon stock dramatically.

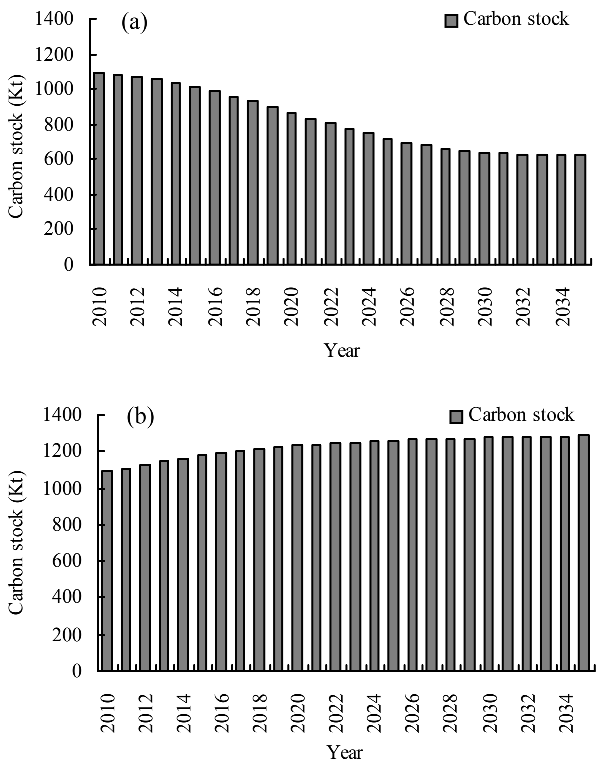


Fig. 8 The carbon stock under (a) Scenario 1, and (b) Scenario 2

Labor requirements

Fig. 9 shows the labor requirements under the different scenarios. Under Scenario 1 the maximum and minimum labor requirements were 77 342 workers in 2020 and 26 912 workers in 2011; the maximum and minimum number of required silviculture workers were 48 625 in 2022 and 5 541 in 2011; the maximum and minimum number of workers for stand thinning were 13 039 in 2019 and 4 822 in 2035; and the maximum and minimum number of forest workers for clear-cutting were 16 904 in 2020 and 8 924 in 2035. Under Scenario 1 the labor requirements for clear-cutting and silviculture were larger than those for thinning, with the ratio of the proportion of total labor required for clear–cutting, to the proportion of the total labor required for thinning ranging from 40:40 in 2011 to 18:10 in 2035. After 2020, the labor requirements decreased by up to 65.2% of their maximum value, although the labor requirements in 2035 were 162.3% of the labor required in 2010. The overall decrease was due to a decrease in the harvesting area (Fig. 4a) for clear-cutting.

Under Scenario 2 the maximum and minimum labor requirements were 48 037 personnel in 2034 and 18 759 in 2011; the maximum and minimum numbers of workers required in silviculture were 16319 in 2034 and 5542 in 2011; the maximum and minimum numbers of people involved in thinning were 25 468 in 2034 and 10 300 in 2010; and the maximum and minimum numbers of clear-cutting forest workers were 6371 in 2035 and 1801 in 2010. Under Scenario 2 the labor required for clear-cutting and silviculture was larger than was required for thinning, with ratios of clear-cutting labor to thinning labor ranging from 8:45 in 2010 to 13:53 in 2035. Labor requirements increased by up to 208.0% of the minimum value between 2010 and 2035, the increase being due to the increase in harvesting area (Fig. 4b).

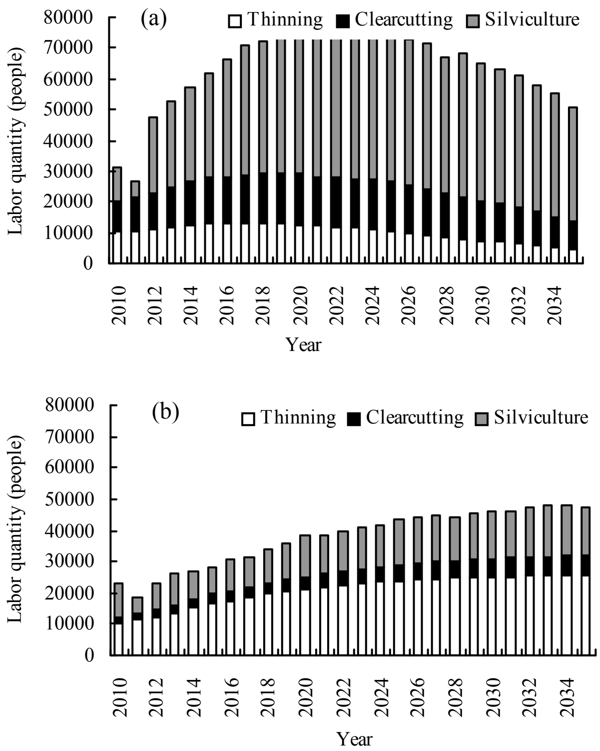


Fig. 9 The labor requirements for silviculture, clear-cutting and thinning under (a) Scenario 1, and (b) Scenario 2. White, black and gray blocks show the thinning, clear-cutting and silviculture labor requirements, respectively.

A comparison of the two scenarios clearly shows that silviculture requires more workers under Scenario 1 than under Scenario 2 with differences ranging between 50 89 and 42 168 personnel. After 2022, the difference in labor requirements for silviculture decreased by up to 62.6% of the maximum value. In contrast, the labor required for thinning was greater under Scenario 2 than under Scenario 1, with differences ranging between 4 150 and 22 716 personnel. These results suggest that the differences in labor requirements under Scenarios 1 and 2 were mainly associated with silviculture practices and thinning, respectively.

Because the estimated subsidies, forestry profits, carbon stocks, and labor requirements are affected by fluctuations in the stand age distribution and the stand condition over time, the observed pattern of increase was not monotonic.

Finally, Fig. 10 shows the cost-effectiveness of investments in

timber production and carbon stock. In terms of timber production, the maximum difference in the cost-effectiveness of Scenarios 1 and 2 was 3.8 in 2011. This relationship was reversed in 2016 and the difference in cost-effectiveness of the two scenarios increased with time. On the other hand, in terms of carbon stock, the maximum difference in the cost-effectiveness of Scenarios 1 and 2 was 30.2 in 2016. In this case, the difference in cost-effectiveness decreased with time after 2016.

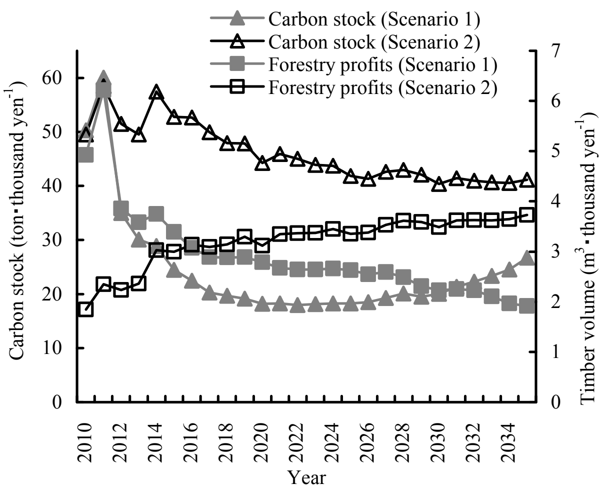


Fig. 10 Cost-effectiveness of industrial timber development and carbon sequestration. Black and white triangles show the cost-effectiveness of carbon stock under Scenarios 1 and 2, respectively. Black and white squares show the cost-effectiveness of timber production under Scenarios 1 and 2, respectively.

Discussion

Our approach enables the effects of different subsidy scenarios on forestry to be calculated. Although timber production is the basic function of forests, their role in storing carbon stock also holds a high position in the public mind, especially during the first commitment period of the Kyoto Protocol. Figs. 5 and 8 enable us to consider the influence of forest management under different subsidy systems on both of these factors. In addition, the simulation results for subsidies and labor requirements can be considered as important practical issues for forest management. Subsidies (Fig. 6) and labor requirements (Fig. 9) under the two scenarios were thus mainly allocated to clear-cutting and thinning (Fig. 4) under Scenarios 1 and 2, respectively. These results suggest that if the clear-cutting area were to decrease (Fig. 4a), the required subsidy (Fig. 6a) and labor (Fig. 9a) would not decrease immediately, because weeding continues to be required for 5 years after planting in the clear-cutting area.

Previous studies have analyzed useful variables and estimated parameters for several econometric models including the probit model (Dennis 1990; Pattanayak et al. 2003) and the logistic regression model (Royer 1987; Zhang and Pearse 1997), which can be used to predict the effects of forestry policies and subsidy systems. Other previous studies (e.g. Lewis and Plantinga 2007; Kurttila et al. 2006; Bolkesjø and Baardsen, 2002) have created models to estimate the effects of different amounts of subsidy. Our simulations also enable us to predict the effect of subsidy scenarios on the forest resources and timber production in targeted Japanese forest plantations.

For instance, in the present study, under Scenario 1 it is feasible to increase timber production during the early period of our predicted output (Fig. 5). However, Scenario 2 is a better option if the forests' function of holding carbon stock is the more pressing and stronger requirement (Fig. 8). The most suitable scenario could be selected by considering practical issues based on labor requirements and subsidies (Figs 6 and 9). As mentioned above, in the case of regional forest areas, the difference in the cost-effectiveness (Fig. 10) of any investment might be comparable during the period over which our predictions are made.

As explained in the introduction, Scenario 2 focuses on expanding the thinning area and restricting the clear-cutting area and so supports long-rotation silviculture as a means of increasing the carbon stock as required under the Kyoto Protocol. A comparison of the simulation results of Scenarios 1 and 2 shows that maintaining the carbon stock is more feasible and cost–effective under Scenario 2 (Fig. 10). Because a larger amount of subsidy is available for silviculture (Fig. 6a) following regenerations in the larger clear-cutting area (Fig. 4a), the cost-effectiveness of timber production under Scenario 1 was lower than under Scenario 2 after 2017 (Fig. 10). However, if the production of a large amount of timber is not an immediate requirement, Scenario 2 can be the better alternative with a lower subsidy budget. Notwithstanding this, in terms of the efficient use of the timber resource, such a choice might be irrational under some circumstances because of the possibility that some profitable stands might then be forced to avoid clear-cutting in order to produce larger timber.

These simulations can help policy makers and forestry practitioners propose policy changes that would not only enhance cost-effective timber production, but also fulfill carbon stock obligations pledged under the Kyoto Protocol. Planted forests in the southern part of Japan where the present study was conducted are highly productive of timber, especially from the main tree species (*Cryptomeria japonica*). Because this species is very broadly distributed (Fukuda et al. 2003), the simulations described here, which are based on real data, could also be applied to planted forests in other regions.

These simulations would therefore be generally useful for planning forest management and aiding decision-making by forestry policy makers under the plan-do-check-act (PDCA) cycle.

A previous study (Nakajima et al. 2007b) has suggested that a PDCA cycle for managing Japanese forests is required, which takes into consideration the cost-effectiveness of investments in the form of subsidies (Fig. 9). Fig. 11 shows a simple outline of the PDCA cycle for forest management based on that study (Nakajima et al. 2007b). Basically, the cycle for forest management depends on the management objective. Although in the present study, we assumed certain values in order to predict the effect of different subsidy systems on timber production and carbon stock, certain socio-economic conditions that are represented by model

parameters, could change. However, because the discount rate is the interest rate used to determine the present value of future cash flows (Eatwell et al. 1987; Winton JR. 1951), it is defined relative to a value that society considers to be reasonable. Although a previous study (van Kooten et al. 1995) has stated that, in general, the higher the discount rate, the shorter the rotation period, it is difficult to predict accurately not only the future timber price but also the discount rate as it might be affected by changing socio-economic conditions. Thus, it would be better to improve forest management plans by inputting into the simulation model parameter values that reflect the current socio-economic conditions, and changes in those socio-economic conditions, including discount rates and timber prices that might prevail in the future. Forest management plans could then be simulated by considering, not only socio-economic conditions, but also forest resource productivity and the age distribution of stands derived from forest inventory data.

After the planning stage, including the securing of the required labor (Do), which can also be predicted in the present study, forest resources, forestry profits, carbon stock etc. could be monitored in order to check the effects of the forest management plan (Check). Such monitoring would provide information on which to base the subsidy for practical funding and a budget could be decided for improving forest management planning (Act). Inputting such information could then be used to simulate an improved forest management plan, taking into consideration any possible socio-economic conditions that might prevail in the future (Plan). By repeating these stages in the PDCA cycle, the effect of subsidies on forest management in maintaining economic and environmental sustainability at a regional level could be continuously and appropriately revised and checked in order to achieve accountability of the public investment in forests.

As mentioned in the introduction, although the PDCA cycle for adaptive management in large forest tracts is encouraged throughout the world, there is little evidence that it is effective at the local scale. Applications of the present analytical tools used to produce these simulations, including those used to predict timber production, carbon stock, and other factors relevant to PDCA management cycles that are dependent on alternative subsidy scenarios, would be useful for decision-makers in other regions if the applications were specified according to particular geographic locations.

In the present paper we have described an approach that is designed to increase information concerning objective economic and environmental outcomes of forest management such as timber volume (Fig. 5), forestry profits (Fig. 7) and carbon stock (Fig.8), as well as information concerning cost-effectiveness (Fig. 10), budgets, operability and subsidies (Fig. 6), labor requirements (Fig. 9) and other factors related to PDCA cycles (Fig. 11). Thus, policy makers could use the information from the simulations designed to understand the influence of different subsidy scenarios on local forestry, to select appropriate plans that would meet their management goals. Other simulation results (e.g. Fig. 10) could be used to decide what information should be taken into consideration when deciding whether or not the benefits of a particular management action would justify the costs of its implementation.

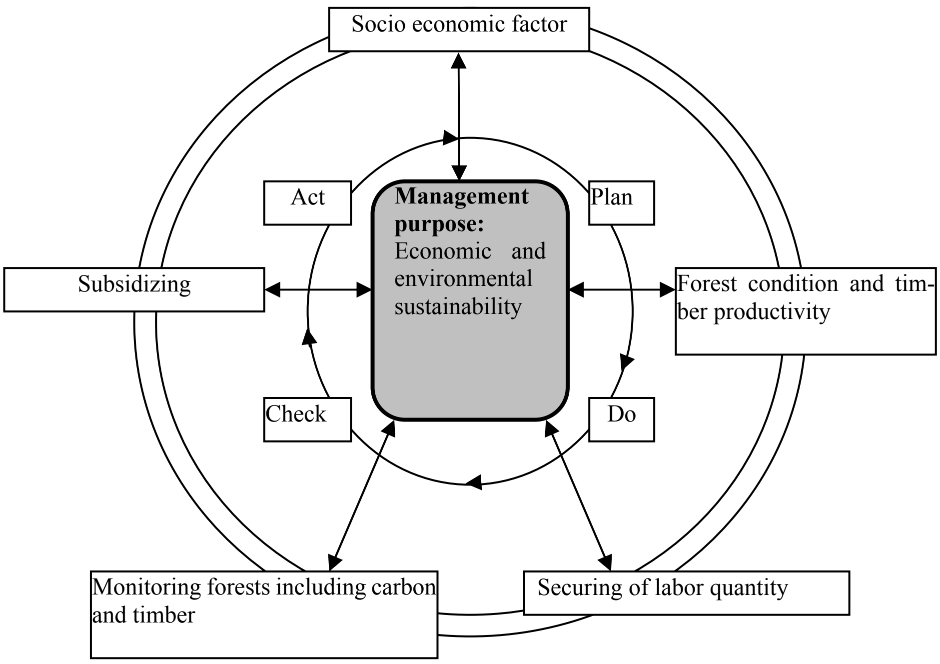


Fig. 11 PDCA cycle for forest management taking into consideration the effect of subsidies on timber production and carbon stock.

Thus, there are several ways in which the simulation proposed in the present study enables us to improve the PDCA cycle. Although there are always uncertainties concerning the future state of socio-economic conditions, the present simulation results can

at least provide information about any future tendency of estimated values to change over the prediction period in response to the subsidy scenario currently being implemented under the present socio-economic conditions. However, because estimates are prone to errors derived from a dramatic change in the socio-economic conditions that pertain to forestry, such as timber price and discount rate, it is important that the actual forest area continues to be monitored in order to check the accuracy of simulations designed to predict future state of forestry. Although our assumptions concerning socio-economic conditions and forest resources were necessarily relatively simple for the preliminary simulation conducted for the present study, as were the patterns of the different subsidy system scenarios, any uncertainty derived from the future changes in socio-economic conditions should be monitored during the management of regional forest resources.

The next challenge is to test the uncertainty of the simulation by monitoring the study area, and to apply the simulation to other forest regions. Depending on the degree of uncertainty and the wider applicability of the simulation, it may be possible to analyze the feasibility of different management strategies and the efficiencies of different subsidy systems according to different regional forest resources, variations in local socio–economic conditions, and diverse forest management goals.

Conclusion

This study used simulation to investigate the effects on timber production and levels of carbon stock, of two scenarios describing alternative subsidy systems applied to Japanese forestry. Simulation output showed that both the harvested thinning area and the volume of harvested timber were larger under Scenario 2, in which the rules governing subsidy allocations are more relaxed, than under Scenario 1, in which the rules governing subsidy allocations are more restrictive. Because harvested timber was mainly produced by clear-cutting under Scenario 1, the forestry profits and the subsidy during the initial prediction period were larger than under Scenario 2. Silviculture subsidies and forestry profits were also larger under Scenario 1 than Scenario 2. However, carbon stocks were smaller under Scenario 1 than under Scenario 2. Reference to previous studies suggests that feasible forest management systems should consider the cost-effectiveness of any subsidy. The simulations may be used to improve the PDCA cycle applied to Japanese forest management systems.

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